

## SEMICONDUCTOR WAFER TEST SYSTEM

### BACKGROUND OF THE INVENTION

The present invention relates to a system and method for  
5 carrying out a non-contact burn-in test on a semiconductor  
wafer.

Recently, the annual production of semiconductor devices  
has been rocketing year after year. Generally speaking, the  
greater the number of devices produced per unit time, the  
10 greater the number of devices with infant mortality to be  
screened out therefrom by an accelerated life test called  
"burn-in", for example. As is well known in the art, a burn-  
in test is carried out on semiconductor devices by subjecting  
the devices to an elevated temperature under an electrical  
15 power stress. Some of the devices that failed to withstand  
the stress are screened out as NO-GOs, while the other de-  
vices that could endure the stress successfully are shipped  
as GOs, or good products. Over the past few years, however,  
the time afforded to develop new semiconductor devices has  
20 been more and more limited. So the burn-in test should also  
be finished in a shorter amount of time. In addition, a wa-  
fer test system for use in such a burn-in test also has to  
have its size further reduced, since the devices under test  
have been downsized almost day after day.

25 The burn-in test has normally been carried out by apply-

ing a stress voltage onto semiconductor devices on a wafer with probe pins brought into contact with the devices under test.

FIG. 14 illustrates how the burn-in test is carried out on a semiconductor wafer 301 including a great number of semiconductor devices thereon using a known wafer test system. As shown in FIG. 14, the wafer 301, supported on a substrate plate 302, is brought into contact with probe pins extending from a probe card 303, and then supplied with a signal delivered from a tester 304 through the pins of the card 303.

Next, it will be described how the wafer test system operates. In the example illustrated in FIG. 14, the plate 302 is grounded at a potential level of 0 V. The wafer 301 is in electrical contact with the plate 302, and each of the numerous devices on the wafer 301 also has its substrate potential fixed at 0 V. In such a state, the tester 304 outputs a signal to devices under test on the wafer 301 by way of the pins of the card 303. The devices under test, which are in contact with the pins of the card 303, start to operate in response to the signal supplied from the tester 304. As a result, a voltage is applied onto the gate electrode of each of those devices (i.e., transistors). That is to say, a voltage stress is generated between the gate electrode of the transistor and the substrate thereof. In this manner, the devices on the wafer 301 are subjected to the burn-in.

However, if test terminals provided for semiconductor devices on a wafer are of a different type from those provided for devices on another wafer, then the known wafer test system should prepare two mutually different types of probe  
5 cards for these two wafers.

### SUMMARY OF THE INVENTION

To avoid such an undesirable situation, the present inventor performed a non-contact burn-in test on semiconductor  
10 devices on a semiconductor wafer without using any probe pins. In this burn-in test, each of the devices under test on the wafer was exposed to a direct-current (DC) electric field so that a voltage was applied onto the gate oxide film of the devices. Hereinafter, with reference to FIG. 10, I  
15 will briefly describe the burn-in test I conducted before describing the summary of my invention. FIG. 10 illustrates a semiconductor wafer test system that I used for the burn-in test. First, the respective elements of the system will be described.

20 As shown in FIG. 10, a semiconductor wafer 501, including a great number of semiconductor devices under the burn-in test, is supported on a substrate plate 502. The burn-in test is carried out by applying a predetermined voltage from a DC power supply 504 to a conductive plate 500 and by exposing the  
25 devices under test on the wafer 501 to an electric field S500

that has been created from the conductive plate 500. The electric field S500 created from the conductive plate 500 has an intensity proportional to the voltage applied from the power supply 504. As a result, a current I501 flows from the  
5 plate 502 into the ground.

FIG. 11 illustrates one of the devices under the burn-in test on the wafer 501 to a larger scale. First, the respective elements of the device will be described. As shown in FIG. 11, the semiconductor device (i.e., an MOS transistor in  
10 this case) to be exposed to the electric field S500 created from the conductive plate 500 has been electrically isolated from adjacent devices by isolation regions 501e and 501f. The device includes gate electrode 501a, gate oxide film 501b, source/drain regions 501c and 501d and p-well 501g. That is  
15 to say, part of the wafer 501 for this device includes the source/drain regions 501c and 501d, p-well 501g and substrate portion 501h.

As also shown in FIG. 11, the wafer 501 is supported on the substrate plate 502. The device is exposed to the electric field S500 that has been created from the conductive  
20 plate 500 by applying a voltage from the DC power supply 504 to the conductive plate 500. A parallel plate capacitor is formed between the conductive plate 500 and gate electrode 501a and another parallel plate capacitor is formed between  
25 the gate electrode 501a and p-well 501g. A leakage resistor

512 exists between the gate electrode 501a and the ground and a current I501 flows from the substrate plate 502 into the ground. In FIG. 11, only one n-channel MOS transistor is illustrated as one of the great many devices on the wafer 501 for the sake of simplicity. Accordingly, the source/drain regions 501c and 501d have been doped with an n-type dopant, while the p-well 501g and substrate portion 501h are of p-type.

The substrate portion 501h is in electrical contact with the grounded substrate plate 502 and is fixed at 0 V. The p-well 501g is in contact with the substrate portion 501h and these regions 501g and 501h are both of p-type. So the p-well 501g is also fixed at 0 V.

When a voltage  $V_0$  (V) is applied to the conductive plate 500, the electric field  $S_{500}$  is created, thereby polarizing the gate electrode 501a and producing a voltage  $V_{a0}$  (V) at the gate electrode 501a. As a result, an electric field stress  $E_a$  (V/m) corresponding to the voltage  $V_{a0}$  (V) is placed on the gate oxide film 501b. Hereinafter, this stress will be analyzed quantitatively.

Suppose the area of the gate electrode 501a is  $S_a$  ( $m^2$ ), the distance between the conductive plate 500 and gate electrode 501a is  $d_1$  (m), the thickness of the gate oxide film 501b is  $d_2$  (m), the permeability between the conductive plate 500 and gate electrode 501a is  $\epsilon_1$  (C/(V·m)) and the perme-

ability of the gate oxide film 501b is  $\epsilon_2$  (C/(V·m)). To simplify the computation, one parallel plate capacitor 510 is supposed to be formed between the conductive plate 500 and gate electrode 501a and another parallel plate capacitor 511 is supposed to be formed between the gate electrode 501a and p-well 501g as schematically illustrated in FIG. 12.

As also shown in FIG. 12, a voltage is applied from the DC power supply 504 to the conductive plate 500, thereby creating the electric field to which the device under test is exposed. A leakage resistor 512 exists between the gate electrode 501a and the ground.

Suppose no current flows through the resistor 512 for a while after the voltage  $V_0$  (V) has been applied to the conductive plate 500. Then, a quantity  $Q_0$  (C) of charge stored on the parallel plate capacitor 510 is given by the following Equation (1):

$$Q_0 = \epsilon_1 \cdot S / d_1 \times (V_0 - V_{a0}) \quad (1)$$

where  $V_{a0}$  (V) is the voltage induced at the gate electrode 501a.

The charge quantity  $Q_0$  can also be obtained by the following Equation (2) using the quantity of charge stored on the parallel plate capacitor 511:

$$Q_0 = \epsilon_2 \cdot S / d_2 \times V_{a0} \quad (2)$$

Combining these Equations (1) and (2) together, the voltage  $V_{a0}$  (V) induced at the gate electrode 501a is given by the

following Equation (3):

$$V_{a0} = \epsilon_1 \cdot d_2 / (\epsilon_2 \cdot d_1 + \epsilon_1 \cdot d_2) \times V_0 \quad (3)$$

Accordingly, the electric field stress  $E_{a0}$  (V/m) given by the following Equation (4):

$$E_{a0} = V_{a0} / d_2 = \epsilon_1 / (\epsilon_2 \cdot d_1 + \epsilon_1 \cdot d_2) \times V_0 \quad (4)$$

is placed on the gate oxide film 501b. Also, the intensity  $E_0$  (V/m) of the electric field S500 is given by the following Equation (5):

$$E_0 = \epsilon_2 / \epsilon_1 \times E_{a0} \quad (5)$$

It should be noted that the gate electrode 501a is grounded weakly due to the existence of metal interconnects and leakage current components. Accordingly, the induced charges gradually disappear with time. So if a DC voltage is applied to the conductive plate 500, then the electric field stress with the intensity  $E_{a0}$  can be placed on the gate oxide film 501b for just a short period of time. To avoid this unwanted situation, if the electric field to be placed on the gate oxide film 501b to carry out the burn-in test is represented by  $E_1$  (V/m), then an electric field intenser than  $E_1$  (V/m) should be placed on the gate oxide film 501b initially.

Hereinafter, it will be described how this semiconductor wafer test system operates. First, the voltage  $V_0$  (V) to be applied to the conductive plate 500 will be considered.

In general, dielectric breakdown should occur even in a gate oxide film 501b with no defects if the gate oxide film

501b were exposed to an excessively high electric field. Accordingly, the voltage  $V_{a0}$  induced at the gate electrode 501a should be set to:

$$V_{a0} = d_2 \cdot E_{10} \quad (6)$$

5 where  $E_{10}$  (V/m) is a critical electric field with an intensity at and under which no dielectric breakdown occurs.

Combining the Equations (3) and (6) together, the critical electric field  $E_{10}$  (V/m) will be placed on the gate oxide film 501b initially if the voltage  $V_0$  given by

$$10 \quad V_0 = (\epsilon_2 \cdot d_1 + \epsilon_1 \cdot d_2) / \epsilon_1 \cdot d_2 \times d_2 \cdot E_{10} \quad (7)$$

is applied to the conductive plate 500.

Next, it will be described how much the electric field decreases its intensity due to the existence of the leakage resistor 512.

15 The capacitance  $c_{511}$  (F) of the parallel plate capacitor 511 is given by

$$c_{511} = \epsilon_2 \cdot S / d_2 \quad (8)$$

Supposing the resistance of the leakage resistor 512 is  $r_{512}$  ( $\Omega$ ), the electric field  $E_a(t)$  (V/m), which will be  
20 placed on the gate oxide film 501b when a period of time  $t$  (s) has passed, is given by

$$E_a(t) = E_{10} \exp(-t / (c_{511} \cdot r_{512})) \quad (9)$$

FIG. 13 illustrates this decrease in electric field intensity with time. The period of time  $t_5$  (s), during which an  
25 electric field equal to or intenser than  $E_1$  (V/m) is placed on



the gate oxide film 501b, is given by

$$t5=c511 \cdot r512 \times \ln(E10/E1) \quad (10)$$

Accordingly, during this period of time  $t5$  (s), an electric field stress with an intensity equal to or greater than the predetermined field intensity  $E1$  (V/m) is continuously placed on the gate oxide film 501b. That is to say, the gate oxide film 501b is subjected to a burn-in test for this period of time  $t5$ .

In this method, however, the time  $t5$  (s) is determined by only four process constants of  $c511$ ,  $r512$ ,  $E10$  and  $E1$ . Accordingly, unless the process conditions are changed, the burn-in period cannot be extended.

In addition, no reverse electric field is applicable to the gate oxide film, so devices with early failures can be screened out far less completely. Furthermore, the current flows through the substrate always unidirectionally except the initial state. Accordingly, not so much stress can be placed on lattice defects that exist either in the substrate or around the interface between the gate electrode and the substrate. Thus, those failures can be screened out only insufficiently.

It is therefore an object of this invention to get the burn-in period changed by various parameters other than those process constants for a semiconductor wafer test system for use in a burn-in test on semiconductor devices.

Another object of this invention is to make a reverse electric field applicable to the devices under test.

Still another object of this invention is to place a sufficiently high voltage stress on lattice defects existing in the substrate or around the substrate/gate electrode interface.

To achieve these objects, according to the present invention, a semiconductor wafer under a burn-in test is exposed to either electromagnetic wave or alternating-current electric field.

Specifically, an inventive semiconductor wafer test system is a system for carrying out a burn-in test on a great number of semiconductor devices that have been formed on a semiconductor wafer. Each said device includes a gate oxide film between a substrate and a gate electrode. The gate electrode is connected to a metal interconnect. The system includes electromagnetic wave generating means. The generating means exposes the wafer to an electromagnetic wave as an alternating current wave and places an electric field with a predetermined intensity on the gate oxide film of each said device on the wafer, thereby carrying out the burn-in test on the devices.

Another inventive semiconductor wafer test system is a system for carrying out a burn-in test on a great number of semiconductor devices on a semiconductor wafer by exposing

the wafer to an alternating-current electric field, not the electromagnetic wave.

In one embodiment of the present invention, the inventive system may include stress sensing means and control means. The stress sensing means senses a voltage stress imposed on the gate oxide film of each said device while the wafer is being exposed to the electromagnetic wave or the alternating-current electric field. The control means controls the intensity of the electromagnetic wave or the alternating-current electric field so that the voltage stress sensed by the stress sensing means falls within a preset threshold value range.

In this particular embodiment, the voltage stress, which has been sensed by the stress sensing means as being imposed on the gate oxide film, preferably includes forward and reverse voltage stresses. The control means preferably controls the intensity of the electromagnetic wave or the alternating-current electric field so that the forward and reverse voltage stresses imposed on the gate oxide film fall within first and second preset threshold value ranges, respectively. In this case, the second range is preferably lower than the first range.

Still another inventive semiconductor wafer test system is a system for carrying out a burn-in test on a great number of semiconductor devices formed on a semiconductor wafer.

Each said device includes a gate oxide film between a substrate and a gate electrode. The gate electrode is connected to a metal interconnect. The system includes electric field generating means and driving means. The generating means includes a conductive plate for exposing the wafer to an electric field as a direct current wave. The generating means sets the electric field placed on the gate oxide film of each said device on the wafer to a predetermined intensity. The driving means loads and unloads the wafer into/from a space where the electric field, generated from the conductive plate, exists. In this manner, the wafer is exposed to an alternating-current electric field to carry out the burn-in test on the devices.

According to the present invention, a semiconductor wafer can be exposed to electromagnetic wave or alternating-current electric field for an interval of a variable length. Thus, a burn-in test can be carried out on semiconductor devices on the wafer for any arbitrary period of time. In addition, a reverse electric field is also applicable to the gate oxide film of each of those devices. Accordingly, devices with failures can be screened out with much more certainty. Also, a sufficient stress can be placed on lattice defects existing in the substrate or around the substrate/gate electrode interface.

Moreover, according to the present invention, a reverse

voltage applied to the gate oxide film of any semiconductor device is set no greater than the maximum allowable reverse voltage of the gate oxide film. Thus, the semiconductor devices can be tested without deteriorating the gate oxide film  
5 of any normal one of the devices.

Furthermore, according to the present invention, the driving means alternately loads and unloads the wafer into/from a space where the electric field generated from the conductive plate exists. Accordingly, it is possible to ex-  
10 pose the semiconductor devices on the wafer to an alternating-current electric field and freely set the burn-in period to any arbitrary length while using a direct current power supply.

#### 15 BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 illustrates an exemplary overall arrangement for a semiconductor wafer test system according to a first embodiment of the present invention.

FIGS. 2A, 2B, 2C, 2D and 2E are timing diagrams illustrating the waveforms of reference current signal, current  
20 flowing, output signal of a tester, output signal of a power supply controller and electromagnetic wave, respectively, in the test system of the first embodiment.

FIGS. 3A, 3B, 3C, 3D and 3E are timing diagrams illustrating the waveforms of reference current signal, current  
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flowing, output signal of a tester, output signal of a power supply controller and electromagnetic wave, respectively, in a semiconductor wafer test system according to a second embodiment of the present invention.

5        FIG. 4 illustrates an exemplary overall arrangement for a semiconductor wafer test system according to a third embodiment of the present invention.

FIG. 5 is a cross-sectional view illustrating the main portion of a semiconductor device under test.

10        FIG. 6 is a schematic representation illustrating how the test system of the third embodiment places an electric field stress on a semiconductor wafer under test.

FIGS. 7A, 7B, 7C, 7D and 7E are timing diagrams illustrating the waveforms of reference current signal, current flowing, output signal of a tester, output signal of a power supply controller and electric field generated from a conductive plate, respectively, in the test system of the third embodiment.

FIGS. 8A, 8B, 8C, 8D and 8E are timing diagrams illustrating the waveforms of reference current signal, current flowing, output signal of a tester, output signal of a power supply controller and electric field generated from a conductive plate, respectively, in a semiconductor wafer test system according to a fourth embodiment of the present invention.

25        FIG. 9 illustrates an exemplary overall arrangement for

a semiconductor wafer test system according to a fifth embodiment of the present invention.

FIG. 10 illustrates an overall arrangement for a semiconductor wafer test system that I modeled.

5 FIG. 11 is a cross-sectional view illustrating the main portion of a semiconductor device under test.

FIG. 12 is a schematic representation illustrating how the test system shown in FIG. 10 places an electric field stress on a semiconductor wafer under test.

10 FIG. 13 is a graph illustrating how the electric field stress placed by the test system shown in FIG. 10 on the wafer under test changes with time.

FIG. 14 illustrates an overall arrangement for a known semiconductor wafer test system.

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#### DESCRIPTION OF THE PREFERRED EMBODIMENTS

Hereinafter, preferred embodiments of the present invention will be described with reference to the accompanying drawings.

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#### EMBODIMENT 1

FIG. 1 illustrates an exemplary overall arrangement for a semiconductor wafer test system according to a first embodiment of the present invention. First, the respective  
25 elements of the system will be described.

As shown in FIG. 1, the test system is for use to carry out a burn-in test on a great number of semiconductor devices that have been formed on a semiconductor wafer 11 supported on a substrate plate 12. The test system includes: electro-  
5 magnetic wave generator 10 for generating an electromagnetic wave S10 to which the wafer 11 should be exposed; and control unit 13 for controlling the generator 10.

Although not shown in FIG. 1, each of those semiconductor devices on the wafer 11 may be a transistor including  
10 substrate, gate electrode and gate oxide film located between the substrate and gate electrode. A metal interconnect is connected to the gate electrode of each transistor. That is to say, the devices on the wafer 11 have already gone through their fabrication process and will be final products when the  
15 wafer 11 is diced into respective chips. To carry out a burn-in test on the devices on the wafer 11 efficiently, the metal interconnect, connected to the gate electrode of each of those transistors, preferably does not cover the gate oxide film thereof. As for the devices on the wafer 11, the same  
20 statements will be applicable to the other embodiments of the present invention.

As shown in FIG. 1, the control unit 13 includes power supply 14, power supply controller 15 and tester 16. The power supply 14 supplies power to the electromagnetic wave  
25 generator 10 to get the electromagnetic wave S10 generated by



the generator 10. The power supply controller 15 controls the power supply 14 by outputting a control signal S15 thereto and is controlled itself in response to a reference current signal S15a supplied thereto. The tester 16 measures a  
5 current I11 flowing between the substrate plate 12 and the ground and outputs a signal S16 to the power supply controller 15.

In response to the output signal S15 of the power supply controller 15, the power supply 14 supplies a current in the  
10 amount proportional to the level of the signal S15 to the electromagnetic wave generator 10. The electromagnetic wave generator 10 generates an electromagnetic wave with an intensity proportional to the amount of current supplied from the power supply 14. If the current value represented by the out-  
15 put signal S16 of the tester 16 is smaller than the preset value represented by the reference current signal S15a, then the power supply controller 15 increases the level of its output signal S15. On the other hand, if the former current value is greater than the latter current value, then the power  
20 supply controller 15 decreases the level of its output signal S15. If these current values are equal to each other, the power supply controller 15 retains the level of its output signal S15. And in the initial state, the power supply controller 15 outputs zero as its output signal S15. The tester  
25 16 measures the alternating current I11 flowing between the

substrate plate 12 and the ground, and outputs the amplitude of the current as its output signal S16 to the power supply controller 15.

The tester 16 of the control unit 13 is an exemplary stress sensing means 18 as defined in the appended claims. That is to say, the tester 16 senses an electric field stress, which is imposed on the gate oxide film of each device on the wafer 11 as a result of the exposure to the electromagnetic wave generated from the electromagnetic wave generator 10, by the current I11 flowing between the substrate plate 12 and the ground. Also, the power supply controller 15 is an exemplary control means 19. Specifically, the power supply controller 15 controls the electric field intensity of the electromagnetic wave, generated by the electromagnetic wave generator 10, so that the current I11, sensed by the stress sensing means 18, falls within a preset threshold value range defined by the reference current signal S15a.

Next, it will be described how the semiconductor wafer test system with such a configuration operates. FIGS. 2A, 2B, 2C, 2D and 2E illustrate the waveforms of the reference current signal S15a supplied to the power supply controller 15, current I11 flowing between the substrate plate 12 and the ground, output signal S16 of the tester 16, output signal S15 of the power supply controller 15 and electromagnetic wave S10 generated from the electromagnetic wave generator 10,

respectively.

In carrying out a burn-in test on the devices on the wafer 11, the substrate plate 12 is grounded at a potential level of 0 V. The wafer 11 is in electrical contact with the substrate plate 12, and each of the numerous devices on the wafer 11 also has its substrate potential fixed at 0 V. In its initial state, the gate electrode of each of those devices is also fixed at 0 V due to the existence of a metal interconnect, connected to the gate electrode, and leakage current components. While the burn-in test is carried out, an alternating current flows between the substrate plate 12 and the ground. This alternating current has a value proportional to the total area of gate electrodes that are exposed to the electromagnetic wave among the gate electrodes of the semiconductor devices. Hereinafter, this relationship will be analyzed quantitatively.

Suppose the electromagnetic wave generated from the electromagnetic wave generator 10 has a frequency of  $f$  (Hz) and an electric field intensity of  $E_0$  (V/m), the area exposed to the electromagnetic wave is  $S$  ( $m^2$ ), the gate oxide film of semiconductor devices has an average thickness of  $d$  (m) and an average gate density is  $D$ . Then, the electric field intensity  $E$  (V/m) of the electromagnetic wave generated from the electromagnetic wave generator 10 at a time  $t$  (s) is given by the following complex notation:

$$E=E_0 \exp(j2\pi ft) \quad (11)$$

where  $j$  is an imaginary unit. When the devices on the wafer 11 are exposed to the electromagnetic wave emitted from the electromagnetic wave generator 10, the total area of gate electrodes included in the exposure range is obtained by  $D \times S$  ( $m^2$ ). Accordingly, the current  $I_{11}$ , flowing from the substrate plate 12 into the ground when the electric field  $E$  is placed on the gate electrodes, is given by

$$\begin{aligned} I_{11} &= \varepsilon \cdot D \cdot S / d \times d \cdot E_0 \exp(j2\pi ft) \\ &= 2\pi f \cdot \varepsilon \cdot D \cdot S \cdot E_0 \exp(j(2\pi ft + \pi/2)) \end{aligned} \quad (12)$$

where  $\varepsilon$  is the permeability. Equation (12) shows that the current  $I_{11}$  flowing is proportional to not only the total gate area of the devices existing in the part of the wafer 11 that is exposed to the electromagnetic wave but also the electric field intensity  $E_0$  (V/m) of the electromagnetic wave. In the burn-in test, the gate oxide film is exposed to an electric field with a predetermined intensity. Accordingly, supposing the reference electric field intensity is  $E_1$  (V/m), when the amplitude of the alternating current  $I_{11}$  given by Equation (12) reaches that of the current  $I_1$  (A) given by

$$I_1 = 2\pi f \cdot \varepsilon \cdot D \cdot S \cdot E_1 \text{ (A)} \quad (13)$$

the burn-in test is completed.

First, the reference current signal  $S_{15a}$  to be supplied to the power supply controller 15 is set to the current  $I_1$  (A). In the initial state, this current  $I_{11}$  is 0 (A), so the

output signal S16 of the tester 16 is also 0 (A). Then, the power supply controller 15 compares the reference current signal S15a to the output signal S16 of the tester 16, thereby increasing its output voltage S15 from the initial value of 0 V. This state corresponds to the time 0 (s) shown in FIG. 2D. As the output voltage S15 of the power supply controller 15 rises, the current supplied from the power supply 14 to the electromagnetic wave generator 10 increases, so does the electric field intensity of the electromagnetic wave generated from the electromagnetic wave generator 10. As a result, the alternating current I11 flowing continuously increases its amplitude in the interval between 0 (s) and the time t1 (s) at which the output signal S16 of the tester 16 reaches the current I1 (A) as shown in FIGS. 2B and 2C.

At the time t1 (s), the output signal S16 of the tester 16 gets equal to the current I1 (A). Accordingly, the power supply controller 15 has its output signal S15 fixed at the current value. As a result, from the time t1 (s) on, a constant amount of current will be supplied from the power supply 14 and the devices on the wafer 11 will be exposed to an electromagnetic wave with a constant electric field intensity.

Next, at a time t2 (s), the reference current signal S15a supplied to the power supply controller 15 is set to 0 (A). Comparing the output signal S16 of the tester 16 to the reference current signal S15a, the power supply controller 15

gradually decreases its output voltage S15. As the output voltage S15 of the power supply controller 15 falls, the current supplied from the power supply 14 to the electromagnetic wave generator 10 decreases, so does the electric field intensity of the electromagnetic wave generated from the electromagnetic wave generator 10. As a result, the alternating current I11 flowing continuously decreases its amplitude in the interval between the time t2 (s) and a time t3 (s) at which the output signal S16 of the tester 16 reaches 0 (A) as shown in FIGS. 2B and 2C. At the time t3 (s), the output signal S16 of the tester 16 reaches 0 (A), which is equal to the value of the reference current signal S15a. Accordingly, the tester 16 has its output signal S16 fixed at 0 (A).

That is to say, in the example illustrated in FIGS. 2A through 2E, a predetermined stress is placed on the devices (i.e., the burn-in test is carried out) only in the interval between the times t1 (s) and t2 (s).

In this manner, a non-contact burn-in test can be carried out according to this embodiment on the devices on the wafer 11. Accordingly, there is no need to use or align a great number of probes or to adjust the contact pressure thereof, thus downsizing the semiconductor wafer test system and shortening the test period. In addition, just by changing the length of the interval between the times t1 and t2, the burn-in period can be set freely. Furthermore, since a reverse

electric field is also placed on the devices, failures can be screened out much more effectively. Also, the current flows bidirectionally through the substrate of each of those devices. Thus, sufficient stress can be placed on lattice defects existing either in the substrate or around the substrate/gate electrode interface. Consequently, devices with failures can be screened out even more effectively.

It should be noted that not just a forward electric field  $E_1$  (V/m) but also a reverse electric field  $-E_1$  (V/m) are placed on the gate oxide film of each of those devices. When exposed to a reverse electric field, the gate oxide film might degrade its characteristics due to movement of carriers. For that reason, care should be taken so as not to place a reverse electric field with an intensity exceeding a maximum allowable value.

## EMBODIMENT 2

Next, a second embodiment of the present invention will be described. A semiconductor wafer test system according to the second embodiment may have the same overall configuration as the counterpart of the first embodiment, and the illustration thereof is omitted. In this second embodiment, the electromagnetic wave generated from the electromagnetic wave generator 10 is applied as electromagnetic pulses to limit the intensity of the reverse electric field placed on the gate ox-

ide film of each semiconductor device to an allowable range.

FIGS. 3A through 3E illustrate a situation where the electromagnetic wave generated from the electromagnetic wave generator 10 is applied as electromagnetic pulses. In this embodiment, the intensity of the forward electric field placed on the gate oxide film of each device is set to the reference value  $E_1$  (V/m) and the maximum allowable intensity of the reverse electric field placed on the gate oxide film is set to  $E_2$  (V/m). In this manner, the duty cycle *Duty* of the electromagnetic pulses is set to

$$\text{Duty} = E_2 / (E_1 + E_2) \quad (14)$$

In the other respects, the system of the second embodiment operates in the same way as the counterpart of the first embodiment. It should be noted that the positive intensity of the electromagnetic pulses, associated with the forward electric field, is  $E_1$  (V/m), while the negative intensity of the electromagnetic pulses, associated with the reverse electric field, is  $-E_2$  (V/m) as shown in FIG. 3E. Thus, according to this embodiment, no reverse electric field with an intensity exceeding its maximum allowable value is placed on the gate oxide film of each semiconductor device.

### EMBODIMENT 3

FIG. 4 illustrates an exemplary overall arrangement for a semiconductor wafer test system according to a third em-



bodiment of the present invention. First, the respective elements of the system will be described.

As shown in FIG. 4, this test system is for use to carry out a burn-in test on a great number of semiconductor devices that have been formed on a semiconductor wafer 101 supported on a substrate plate 102. The test system includes: conductive plate 100 for generating an electric field S100 to which the wafer 101 should be exposed; and control unit 103 for controlling an alternating-current (ac) voltage to be applied to the conductive plate 100. The control unit 103 includes power supply 104, power supply controller 105 and tester 106. The power supply 104 applies an ac voltage to the conductive plate 100. The power supply controller 105 controls the power supply 104 by outputting a control signal S105 thereto and is controlled itself in response to a reference current signal S105a supplied thereto. The tester 106 measures a current I101 flowing between the substrate plate 102 and the ground and outputs a signal S106 to the power supply controller 105.

In response to the output signal S105 of the power supply controller 105, the power supply 104 supplies an ac voltage, whose amplitude is proportional to the level of the output signal S105, to the conductive plate 100. The conductive plate 100 generates an electric field S100 with an intensity proportional to the voltage applied from the power

supply 104. If the current value represented by the output signal S106 of the tester 106 is smaller than the preset one represented by the reference current signal S105a, then the power supply controller 105 increases the level of its output  
5 signal S105. On the other hand, if the former current value is greater than the latter current value, then the power supply controller 105 decreases the level of its output signal S105. If these current values are equal to each other, the power supply controller 105 retains the level of its output  
10 signal S105. And in the initial state, the power supply controller 105 outputs zero as its output signal S105. The tester 106 measures the alternating current I101 and outputs the amplitude of the current as its output signal S106 to the power supply controller 105.

15 The power supply 104 and power supply controller 105 of the control unit 103 and the conductive plate 100 together functions as electric field generating means 107 for exposing the devices on the wafer 101 to an electric field with an intensity proportional to the ac voltage to carry out a burn-in  
20 test on the devices. Also, the tester 106 of the control unit 103 is an exemplary stress sensing means 108 as defined in the appended claims. That is to say, the tester 106 senses the electric field stress, which is placed on the devices on the wafer 101 as a result of the exposure to the  
25 electric field generated from the electric field generating

means 107, by the current I101 flowing between the substrate plate 102 and the ground.

FIG. 5 illustrates part of the circle A1 shown in FIG. 4, including part of the conductive plate 100, some of the devices under the burn-in test on the wafer 11 and part of the substrate plate 102, to a larger scale. As shown in FIG. 5, the semiconductor device (i.e., an MOS transistor in this case) has been electrically isolated from adjacent devices by isolation regions 101e and 101f. The device includes gate electrode 101a, gate oxide film 101b, source/drain regions 101c and 101d and p-well 101g. That is to say, part of the wafer 101 for this device includes the source/drain regions 101c and 101d, p-well 101g and substrate portion 101h. As also shown in FIG. 5, the wafer 101 is supported on the substrate plate 102. The device is exposed to the electric field S100 that has been created from the conductive plate 100 by applying an ac voltage from the power supply 104 to the conductive plate 100. A parallel plate capacitor 110 is formed between the conductive plate 100 and gate electrode 101a and another parallel plate capacitor 111 is formed between the gate electrode 101a and p-well 101g. A leakage resistor 112 exists between the gate electrode 101a and the ground, and a current I101 flows from the substrate plate 102 into the ground. In FIG. 5, only one n-channel MOS transistor is illustrated as one of the great many devices on the wafer 101 for the sake of

simplicity. Accordingly, the source/drain regions 101c and 101d have been doped with an n-type dopant, while the p-well 101g and substrate portion 101h are of p-type.

The substrate portion 101h is in electrical contact with the grounded substrate plate 102 and is fixed at 0 V. The p-well 101g is in contact with the substrate portion 101h and these regions 101g and 101h are both of p-type. So the p-well 101g is also fixed at 0 V. When a voltage  $V$  (V) is applied to the conductive plate 100, the electric field  $S_{100}$  is created, thereby polarizing the gate electrode 101a and inducing a voltage  $V_a$  (V) at the gate electrode 501a. As a result, an electric field stress  $E_a$  (V/m) proportional to the voltage  $V_a$  (V) is placed on the gate oxide film 101b. Hereinafter, this stress will be analyzed quantitatively.

Suppose the area of the gate electrode 101a is  $S_a$  ( $m^2$ ), the distance between the conductive plate 100 and gate electrode 101a is  $d_1$  (m), the thickness of the gate oxide film 101b is  $d_2$  (m), the permeability between the conductive plate 100 and gate electrode 101a is  $\epsilon_1$  (C/(V·m)) and the permeability of the gate oxide film 101b is  $\epsilon_2$  (C/(V·m)). To simplify the computation, one parallel plate capacitor 110 is formed between the conductive plate 100 and gate electrode 101a and another parallel plate capacitor 111 is formed between the gate electrode 101a and p-well 101g as shown in

FIG. 6.

FIG. 6 is a schematic representation of the structure shown in FIG. 5. As also shown in FIG. 6, an ac voltage is applied from the power supply 104 to the conductive plate 100, thereby creating the electric field to which the devices will be exposed. A leakage resistor 112 exists between the gate electrode 101a and the ground.

The capacitance values  $c_{110}$  (F) and  $c_{111}$  (F) of the parallel plate capacitors 110 and 111 are given by

$$c_{110} = \epsilon_1 \cdot S / d_1 \quad (15)$$

$$c_{111} = \epsilon_2 \cdot S / d_2 \quad (16)$$

Supposing the resistance value of the leakage resistor 112 is  $r_{112}$  ( $\Omega$ ) and the voltage applied to the conductive plate 100 is  $V(t)$  (V), the voltage  $V_a(t)$  (V) placed on the gate oxide film 101b is given by the differential equation:

$$V_a(t) = r_{112} \cdot c_{110} (dV(t)/dt) - r_{112} \cdot (c_{110} + c_{111}) \times (dV_a(t)/dt) \quad (17)$$

Next, it will be described how the test system with such a configuration operates. FIGS. 7A, 7B, 7C, 7D and 7E illustrate the waveforms of the reference current signal S105a, current I101 flowing, output signal S106 of the tester 106, output signal S105 of the power supply controller 105 and electric field S100, respectively.

The substrate plate 102 is grounded at a potential level of 0 V. The wafer 101 is in electrical contact with the substrate plate 102, and each of the numerous devices on the wa-

fer 101 also has its substrate potential fixed at 0 V. In its initial state, the gate electrode 101a of each of those devices is also fixed at 0 V due to the existence of a metal interconnect and leakage current components. While the burn-in test is carried out, an alternating current flows between the substrate plate 102 and the ground. This alternating current has a value proportional to the total area of gate electrodes 101a that are exposed to the electric field among the gate electrodes 101a of the devices. Hereinafter, this relationship will be analyzed quantitatively.

Suppose the voltage applied to the conductive plate 100 has a frequency of  $f$  (Hz) and amplitude of  $V_0$  (V), the area exposed to the electric field is  $S$  ( $m^2$ ) and the devices have an average gate density of  $D$ . Then, the voltage  $V(t)$  (V) applied to the conductive plate 100 at a time  $t$  (s) is given by the following complex notation:

$$V(t) = V_0 \exp(j2\pi ft) \quad (18)$$

where  $j$  is an imaginary unit. Accordingly, the voltage  $V_a(t)$  (V) placed on the gate oxide film 101b at the time  $t$  (s) is given by

$$V_a(t) = V_{a0} \exp(j2\pi ft) \quad (19)$$

Combining Equations (15) and (19) together, the voltage  $V_{a0}$  (V) produced at the gate electrode 101a is given by

$$V_{a0} = r_{l12} \cdot c_{l10} / (r_{l12} \cdot (c_{l10} + c_{l11}) + 1/j2\pi f) \times V_0 \quad (20)$$

If the frequency  $f$  (Hz) is set equal to or greater than

$1/r_{112}(c_{110}+c_{111})$ , the intensity of the electric field  $E_a(t)$  (V/m) placed on the gate oxide film 101b is given by

$$E_a(t) = V_a(t)/d_2 = E_{a0} \exp(j2\pi ft) \quad (21)$$

in accordance with Equations (19) and (20). On the other hand, the intensity of the electric field  $E_{a0}$  (V/m) placed on the gate electrode 101a is given by

$$E_{a0} = 1/d_2 \times c_{110}/(c_{110}+c_{111}) \times V_0 \quad (22)$$

When the devices on the wafer 101 are exposed to the electric field created from the conductive plate 100, the total area of gate electrodes included in the exposure range is obtained by  $D \times S$  ( $m^2$ ). Accordingly, the current  $I_{101}$ , flowing between the substrate plate 102 and the ground when the voltage  $V(t)$  (V) is applied to the conductive plate 100, is given by

$$\begin{aligned} I_{101} &= 2\pi f \cdot c_{110} \cdot c_{111}/(c_{110}+c_{111}) \cdot D \cdot S \cdot V_0 \exp(j(2\pi ft + \pi/2)) \\ &= 2\pi f \cdot c_{111} \cdot D \cdot S \cdot d_2 \cdot E_{a0} \exp(j(2\pi ft + \pi/2)) \end{aligned} \quad (23)$$

Equation (23) shows that the current  $I_{101}$  flowing is proportional to not only the total gate area of the devices existing in the range exposed to the electric field but also the amplitude  $V_0$  (V) of the voltage applied to the conductive plate 100.

When an excessively intense electric field is placed on the gate oxide film 101b, breakdown will occur even if the gate oxide film 101b has no defects. Accordingly, supposing a critical electric field, below which no breakdown occurs in

the gate oxide film 101b, is  $E_{10}$  (V/m), it can be seen from Equation (23) that when the amplitude of the alternating current I101 reaches the current value I1 (A) given by

$$I1 = 2\pi f \cdot c_{111} \cdot D \cdot S \cdot d_2 \cdot E_{10} \quad (24)$$

5 the critical electric field  $E_{10}$  should be placed on the gate oxide film 101b.

Next, it will be described with reference to FIGS. 7A through 7E how to perform a burn-in test with the critical electric field  $E_{10}$  placed on the gate oxide film 101b. This test is carried out as in the first embodiment illustrated in FIGS. 2A through 2E. So this test will be briefly outlined below. First, the reference current signal S105a is set to the current value I1 (A). In the initial state, the current I101 flowing is 0 (A). Then, the power supply controller 105 increases its output voltage S105 from the initial value of 0 V. As the output voltage S105 of the power supply controller 105 rises, the voltage applied from the power supply 104 to the conductive plate 100 increases, so does the intensity of the electric field S100 created from the conductive plate 100. As a result, the current I101 flowing increases its amplitude. At the time  $t_1$  (s), the output signal S106 of the tester 106 gets equal to the current I1 (A). Accordingly, the power supply controller 105 has its output signal S105 fixed at the current value. As a result, in the interval between the times  $t_1$  (s) and  $t_2$  (s), a constant ac voltage is applied from the



power supply 104 and the devices on the wafer 101 are exposed to an electric field with a constant intensity. And the critical electric field  $E_{10}$  (V/m) is placed on the gate oxide film 101b thereof.

5        Thereafter, at a time  $t_2$  (s), the reference current signal S105a is set to 0 (A). Accordingly, the power supply controller 105 gradually decreases its output signal S105. As the output voltage S105 of the power supply controller 105 falls, the voltage applied from the power supply 104 decreases, so does the intensity of the electric field S100 created from the conductive plate 100. As a result, the alternating current I101 flowing decreases its amplitude. When the current I101 goes 0 (A) at a time  $t_3$  (s), the tester 106 will have its output signal S106 fixed at 0 (A).

15        That is to say, in the example illustrated in FIGS. 7A through 7E, supposing the current I101 sensed by the tester 106 is the maximum (or threshold) current value given by Equation (24) (i.e., where the maximum electric field placed on the gate oxide film 101b is equal to the critical electric field  $E_{10}$  (V/m)), an electric field with an intensity changing as a sine function is emitted from the conductive plate 100 toward the devices in the interval between the times  $t_1$  (s) and  $t_2$  (s). As a result, a predetermined electric field stress is placed on the semiconductor devices. Strictly speaking, the burn-in test has been carried out for a period

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in which the intensity of the electric field placed on the gate oxide film 101b is greater than the minimum required electric field  $E_1$  (V/m) and less than the critical electric field  $E_{10}$  (V/m). That is to say, the burn-in test period  $T$  (s) is given by

$$T = (t_2 - t_1) \times (1/2 - \alpha/\pi) \quad (25)$$

where  $\sin \alpha = E_{10}/E_1$ . Accordingly, if the interval between the times  $t_1$  and  $t_2$  is set longer, then the burn-in test can be carried out for a longer time. Furthermore, since a reverse electric field is also placed on the gate oxide film, failures can be screened out much more effectively. Also, the current flows bidirectionally through the substrate of each of those devices. Thus, sufficient stress can be placed on lattice defects existing either in the substrate or around the substrate/gate electrode interface. Consequently, devices with failures can be screened out even more effectively.

#### EMBODIMENT 4

Next, a fourth embodiment of the present invention will be described. In this embodiment, to carry out a burn-in test without degrading the normal gate oxide film 101b of any device on the wafer 101 shown in FIG. 4, the critical electric field  $E_{10}$  is not placed as a forward electric field on the gate oxide film 101b and no reverse electric field with an intensity exceeding a maximum allowable value is placed on the

gate oxide film 101b.

The fourth embodiment is different from the third embodiment just in the way the control unit 103 shown in FIG. 4 controls the applied voltage. That is to say, the semiconductor wafer test system of the fourth embodiment also has the overall configuration shown in FIG. 4 and the detailed description thereof will be omitted herein. As for this fourth embodiment, it will be described with reference to FIG. 4 just how the control unit 103 controls the voltage applied to the conductive plate 100.

In the control unit 103, the power supply 104 applies voltage pulses, whose amplitude is proportional to the output signal S105 of the power supply controller 105, to the conductive plate 100. FIGS. 8A through 8E illustrate a situation where the electric field is created as pulses from the conductive plate 100. Supposing the maximum allowable reverse electric field that can be placed on the gate oxide film 101b of each device is  $E_3$  (V/m), the duty cycle Duty of each voltage pulse is set to

$$\text{Duty} = E_3 / (E_1 + E_3) \quad (26)$$

As shown in FIG. 8E, each interval in which the forward minimum required electric field  $E_1$  (V/m) is placed on the gate oxide film 101b is set shorter than each interval in which the reverse electric field  $E_3$  (V/m) is placed thereon. In the other respects, the test system of the fourth embodiment oper-

ates in the same way as the counterpart of the third embodiment.

It should be noted that the positive intensity of the forward electric field placed on the gate oxide film 101b is  $E_1$  (V/m), while the negative intensity of the reverse electric field is  $-E_3$  (V/m) as shown in FIG. 8E. Thus, according to this embodiment, no reverse electric field with an intensity exceeding its maximum allowable value  $E_3$  (V/m) is placed on the gate oxide film 101b. Also, the electric field is placed as pulses on the gate oxide film 101b. So the electric field placed on the gate oxide film 101b does not have to be equal to the critical electric field  $E_{10}$  (V/m) but may be equal to the minimum required electric field  $E_1$  (V/m). Accordingly, there is no concern about the degradation of any normal gate oxide film 101b.

#### EMBODIMENT 5

Hereinafter, a fifth embodiment of the present invention will be described. FIG. 9 illustrates an exemplary overall arrangement for a semiconductor wafer test system according to the fifth embodiment. First, the respective elements of the system will be described.

As shown in FIG. 9, this test system is for use to carry out a burn-in test on a great number of semiconductor devices that have been formed on a semiconductor wafer 401 supported

on a substrate plate 402. In this embodiment, the substrate plate 402 is secured to a drive shaft 407 so as to get driven by a motor 408. The test system further includes: conductive plate 400 for generating an electric field S400 to which the wafer 401 should be exposed; and control unit 403 for controlling a voltage to be applied to the conductive plate 400. The control unit 403 includes dc power supply 404, power supply controller 405 and tester 406. The power supply 404 applies a dc voltage to the conductive plate 400. The power supply controller 405 controls the power supply 404 by outputting a control signal S405 thereto and is controlled itself in response to a reference current signal S405a supplied thereto. The tester 406 measures a current I401 flowing between the substrate plate 402 and the ground, and outputs a signal S406 to the power supply controller 405.

In response to the output signal S405 of the power supply controller 405, the power supply 404 applies a dc voltage, whose amplitude is proportional to the output current S405, to the conductive plate 400. The conductive plate 400 generates an electric field S400 with an intensity proportional to the voltage applied from the power supply 404. If the current value represented by the output signal S406 of the tester 406 is smaller than the preset one represented by the reference current signal S405a, then the power supply controller 405 increases the level of its output signal S405. On the

other hand, if the former current value is greater than the latter current value, then the power supply controller 405 decreases the level of its output signal S405. If these current values are equal to each other, the power supply controller 5 405 retains the level of its output signal S405. And in the initial state, the power supply controller 405 outputs zero as its output signal S405. The tester 406 measures the alternating current I401 flowing between the substrate plate 402 and the ground and outputs the amplitude of the current as its 10 output signal S406 to the power supply controller 405.

The drive shaft 407 is horizontally spaced apart from the wafer 401, while the motor 408 rotates the drive shaft 407 at a constant angular velocity  $\omega$  (rads/s). Accordingly, while the substrate plate 402 is being rotated by the motor 408 15 around the drive shaft 407, the wafer 401 is loaded and unloaded into/from the space, in which the electric field S400 created from the conductive plate 400 exists, at regular intervals.

Next, it will be described how the test system of the 20 fifth embodiment operates. As described above, the wafer 401 is sufficiently spaced apart from the drive shaft 407. Accordingly, while the devices on the wafer 401 are passing under the conductive plate 400, the devices are exposed to the electric field S400. However, once the wafer 401 has gone out 25 of the space under the conductive plate 400, the devices are

exposed to no electric field at all.

Thus, if the ratio of the interval in which the wafer 401 exists inside the electric field S400 under the conductive plate 400 to the interval in which the wafer 401 is located  
5 outside of the electric field S400 is set to the predetermined ratio of

$$E3/(E1+E3):E1/(E1+E3) \quad (27)$$

then a pulsed electric field will be placed on the devices as in the fourth embodiment.

10 Accordingly, if the reference current signal S405a is supplied in such a manner as to place the minimum required electric field E1 (V/m) on the gate oxide film during the burn-in test as in the fourth embodiment, then a predetermined stress will be placed on the devices. As a result, the  
15 burn-in test can be carried out as in the fourth embodiment.

In the third and fourth embodiments, an ac voltage should be applied to the conductive plate 100. In contrast, according to this fifth embodiment, a dc voltage may be applied to the conductive plate 400. This is because the electric field changes for the wafer 401 as the wafer 401 is  
20 rotated by the motor 408.

Thus, according to the fifth embodiment, even though a dc power supply is used as the power supply 404, the burn-in period can be changed using parameters other than the process  
25 constants. Also, no reverse electric field with an intensity

exceeding the maximum allowable value will be placed on the gate oxide film. In addition, the voltage stress is applied as pulses, the electric field placed on the gate oxide film does not have to be equal to the critical electric field  $E_{10}$  (V/m) but may be the minimum required electric field  $E_1$  (V/m). Accordingly, there is no concern about the degradation of any normal gate oxide film.

Thus, the test system of the fifth embodiment can also change the burn-in period freely without changing the process constants. In addition, a reverse electric field is also placed on the devices, so devices with failures can be screened out much more effectively. Furthermore, sufficient stress can be placed on lattice defects existing either in the substrate or around the substrate/gate electrode interface. Consequently, devices with failures can be screened out even more effectively.

In the foregoing embodiments, the present invention has been described as being applied to an n-channel MOS transistor. Naturally, the present invention is equally applicable to a p-channel MOS transistor.